GLOBAL CHANGE

Middle atmosphere cooling

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CHANGES in a thin layer of sodium vapour, about 90 km above the Earth's surface, could be revealing the far-reaching effects of greenhouse gases, B. Clemesha, D. Simonich and P. Batista suggest in *Geophysical Research Letters*[1]. The authors have been monitoring the layer since 1972, and find that by 1987 its mean height had fallen by nearly a kilometre. They attribute the drop to greenhouse gases, which besides warming the lower atmosphere, can actually cool the middle atmosphere.

Although the mesospheric sodium layer was discovered more than 60 years ago, most geophysicists have tended to regard it as a curiosity, if indeed they were aware of its existence. It is believed to be produced by ablation of meteorites as they enter the atmosphere. The amount of sodium in question is very small — maximum concentrations reach only 3–4 thousand atoms per cm^3 near an altitude of 90 km, or less than 0.1 parts per billion by volume.

Nevertheless, the layer is easily detected from the ground because of the strong emission by the orange sodium doublet (at a wavelength of 589–589.6 nm). It is now known that the sodium layer is sharply peaked near a height of 90 km, with a width at half-maximum of about 10 km. Theoretical studies and numerical models suggest that the sharpness of the layer is due to removal of atomic sodium below 90 km by the reaction $Na + O_2 + M \rightarrow NaO_2 + M$, where M is any inert molecule. Above 90 km, photoionization and charge exchange processes produce Na^+, which is thought to be removed ultimately by incorporation into hydrates.

Lidar ranging

Clemesha and his colleagues have been making lidar (laser-infrared ranging) measurements of the mesospheric sodium layer from São José dos Campos, Brazil, since 1972. In their new paper, they report that the height of the centroid of the sodium distribution has decreased by 49±12 m a year, or a little over 700 m over the period 1972–87. To connect this finding with global cooling of the middle atmosphere, the authors note that a uniform cooling of 5 K at all altitudes above 50 km would be sufficient to account, through contraction of the atmosphere, for a lowering of about 700 m of constant-density surfaces in the vicinity of 90 km. The altitude at which meteorites ablate and deposit sodium depends on atmospheric density, so a lowering of the density surfaces would cause a corresponding lowering of the source of sodium and, presumably, a decrease is the mean altitude of the sodium layer. Clemesha and colleagues suggest that the required temperature decrease is consistent with some estimates of temperature trends in the stratosphere and lower mesosphere[2].

Global cooling of the middle atmosphere due to increasing concentrations of greenhouse gases has been predicted by several investigators from the results of numerical models. In a recent paper, Roble and Dickinson[3] showed that the same gases (CO_2, nitrous oxide, methane, fluorocarbons) that produce the greenhouse effect in the troposphere also cool the upper layers of the atmosphere by increasing the amount of infrared radiation emitted to space. The work of Brasseur and Hitchman[4] leads to similar conclusions for the entire layer between heights of 25 and 70 km. Whereas Roble and Dickinson studied the response of the upper mesosphere and thermosphere, the results of Brasseur and Hitchman are, if anything, more relevant to the hypothesis put forward by Clemesha and colleagues because they demonstrate that global cooling should occur throughout most of the stratosphere and mesosphere.

For a doubling of atmospheric CO_2 (and corresponding increases in the concentrations of other radiatively important trace gases), the numerical models predict temperature decreases in the middle atmosphere ranging from 2–3 K at 25 km to more than 20 K near 45 km. Above this altitude, the calculated cooling decreases to a minimum in the upper mesosphere before increasing sharply again in the thermosphere above 90 km. However, these predictions are based upon estimates of the expected concentration of greenhouse gases at the end of the next century. Cooling of the middle atmosphere resulting from the increases in greenhouse gases that have taken place over the past 15–20 years should be substantially smaller — a maximum of 2–2.5 K near 45 km and proportionally lesser amounts elsewhere. These figures are in broad agreement with analyses of temperature trends performed by the International Ozone Trends Panel[5], which indicate that temperatures decreased by about 2 K in the upper stratosphere and lower mesosphere during the 1980s.

Although models and observations both lend qualitative support to Clemesha and colleagues' suggestion, the best estimates of temperature decreases in the middle atmosphere appear to be too small to produce the effect claimed by these authors. In particular, the maximum temperature decrease at any altitude in the middle atmosphere during the period 1972–87 should be about 2 K, whereas Clemesha and colleagues require a uniform change of 5 K between 50 and 90 km. Even if one assumes that, as predicted by the numerical models, temperature decreases occur everywhere between 25 km and 90 km, and that their average magnitude over this range of altitudes is as large as 1 K, constant density surfaces in the vicinity of 90 km would be lowered by only 250 m, just a third of the change reported for the sodium layer.

Removal processes

But Clemesha and colleagues do not consider the influence of removal mechanisms on the vertical distribution of sodium. The input of meteoric sodium[6] is rather sharply peaked at about 82 km, but the layer itself is centred at 90 km. This implies that the altitude of the layer depends strongly on the vertical distribution of removal processes and not just on the altitude at which meteors ablate. The rapid decrease of sodium below the peak at 90 km is believed to be due to removal by its three-body reaction with oxygen, whose efficiency varies as the square of atmospheric density. When this dependence is taken into account, a simple calculation assuming a 1 K temperature drop between 25 and 90 km yields a decrease of over 500 m in the altitude of the sodium peak, not far off the 700 m reported by Clemesha and colleagues.

Although it is not possible to state with absolute certainty that the decrease in the altitude of the sodium layer is an indication of global cooling in the middle atmosphere, the behaviour of the layer clearly bears systematic watching in years to come. Like the apparent increase in the frequency of polar mesospheric clouds reported recently in this journal by Thomas *et al.*[7] and attributed to increases in mesospheric water vapour, it may be that the initial signs of global change are to be sought in the upper reaches of the atmosphere. □

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